Explaining the Neolithic Demographic Transition

Jean-Pierre Bocquet-Appel

Abstract Three main questions are raised in this chapter.

1. The part of the signal of the NDT which is demographically identifiable, based on the proportion of the immature skeletons in cemeteries, shows that a baby-boom occurred and, beyond that, with the onset of the change in the economic system, a fertility transition towards high values also occurred. What was the biodemographic cause of this fertility explosion, beyond the proxy variable represented by sedentarism? The cause is a major shift in the maternal energetics of farming communities relative to mobile foragers. In the energy balance there was (i) on the intake side, an underlying trend towards a reduction in low-calorie food from hunting and fishing, and a correlative increase in high-calorie food from agriculture, (ii) on the expenditure side, a reduction in the physical energy devoted to mobility and the maternal stress of child transportation.
2. The NDT is detectable from a signal representing a fertility transition, but the transition relating to mortality is missing and must be inferred. If, during the fertility transition, mortality had remained the same as in the preceding forager period, then the population would have grown infinitely. The assumption of un-changed mortality during the entire fertility transition is therefore not realistic. Mortality, in its turn, must have begun to rise well before the end of the fertility transition. But when? Why? One of the answers consists of a model where, except at the start of the process, birth and mortality rates rise more or less simultaneously, bringing about a typical rate of increase for pre-industrial populations of slightly above zero.
3. According to the level and speed of the population growth, what should we expect in terms of population structure? What are the expected effects of this growth, not only on the population in numbers but also on age distribution, the distribution and structure of families, the distribution of households and on family systems?

J.-P. Bocquet-Appel

Centre National de la Recherche Scientifique (CNRS), UPR2147, 44, rue de l'Amiral Mouchez – 75014 Paris, France, bocquet-appel@ivry.cnrs.fr

Introduction

The signal of a major demographic shift during the transition from forager-horticulturists to farmers in Europe, North Africa and North America was detected in palaeoanthropological data from more than 120 cemeteries. This signal, which is characterised by a relatively abrupt increase in the proportion of immature skeletons, has been named the Neolithic demographic transition (NDT) (Bocquet-Appel and Naji 2006, Bocquet-Appel 2002, Bocquet-Appel and Paz de Miguel Ibanez 2002). The demographically identifiable part of the signal indicates a sharp increase in the birth rate, and beyond, a transition towards higher fertility values than those characterising the preceding forager period. This NDT raises a number of questions, starting with the cause of the increase in fertility. Because of its overall impact on the fertility of populations that turned to farming, wherever they were located on the planet, we would expect one or more identical causes having a determining effect on the variability of fertility, which should contribute to their identification.

Assumption number one, which was formulated a long time ago, is the impact of sedentism on fertility in nomadic forager populations (Lee 1972b, 1979, Binford and Chasko 1976, Sussman 1972, Binford 1968, Carr-Saunders 1922, Malthus 1798). Although this is a broad assumption, it tends to be borne out by the few data we have on nomadic populations in the process of sedentism (Binford and Chasko 1976, Romaniuk 1981, Roth 1981, Roth and Ray 1985), which are outlined below. The same applies to archaeological data representing the cemeteries of forager and farming populations, whose putative gradient of mobility from nomadic to sedentary (see below) closely coincides with the expected birth rate estimates. However, this broad assumption is a proxy variable for other underlying biodemographic variables that come into play. Which are these? In this chapter, the model of the relative metabolic hypothesis (for a summary see Valeggia and Ellison 2004), which is used in order to integrate the physical constraints of mobility, breastfeeding and maternal nutrition, is set forth to explain the variation in fertility during the NDT.

The second question raised by the NDT concerns its scenario. The NDT is detectable from a signal representing a shift towards higher fertility values, but the mortality part of the signal is missing and must be inferred. It is as if, in the contemporary demographic transition (CDT), only the profile representing the drop in birth rate was known, so that the drop in mortality would have to be estimated from this. The contemporary transition has multiplied the world's population by six in 150 years. So what should be done? In order to build up the scenario of the NDT, we need a model. The universal density-dependent (or homeostatic) demographic model is used. From an updated sample of Old and New World cemeteries in the northern
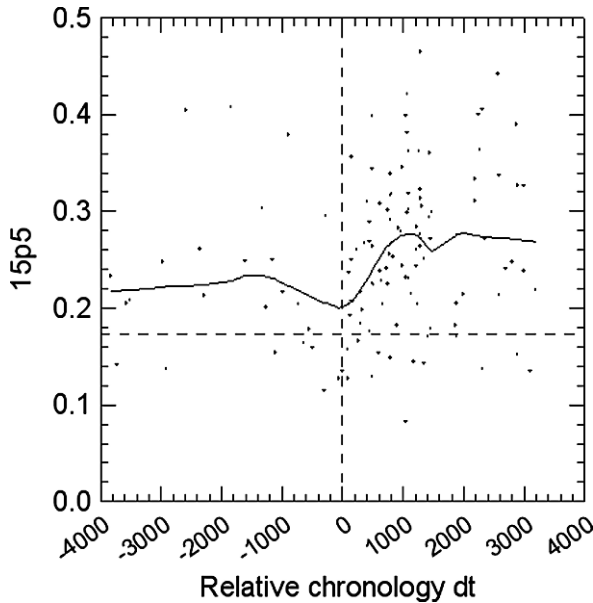
Fig. 1 Observed profile of the $_{15}p_5$ indicator in the northern hemisphere (133 sites, $N \geq 50$)

hemisphere (133 cemeteries; see Fig. 1), a birth rate estimate is obtained ranging from 40.3 to 53.1 per 1000, over 1000 years during the Neolithic fertility transition (see below). If, during the fertility transition, mortality had remained the same as in the preceding forager period (≤ 40.29 per 1000), then the population would have reached an unrealistic number. The assumption of unchanged mortality throughout the fertility transition is therefore unrealistic. Mortality must have increased in turn well before the end of the fertility transition. But when and why did this happen? What timing for birth and mortality rates should we put in the NDT scenario? How should this scenario be tested, and with what data?

The third question, which follows on from the model of the NDT, concerns the impact of population growth on the population itself and its cultural expression. What were the effects of this growth, not only on population numbers but also on the various aspects of its evolving structure such as age distribution, the distribution and composition of families, the distribution of households, family systems (extended or nuclear) and the institutions developed to regulate tensions between groups/individuals in a steadily growing population?

In the first part on "experimental demographics", the model of the relative metabolic load is tested with an ethnographic sample of 172 populations of western North American Indians (Jorgensen 1979, 1999). In the second part, we explore a model of the NDT where birth rate and mortality evolve in tandem, producing a growth rate slightly above zero. In the third part, the effects of this demographic growth on the population structure are briefly reviewed.

Putative Cause of the Neolithic Fertility Transition

Direction of Fertility Change During the Transition to Sedentarism

Thirty years ago, the archaeologists and anthropological demographers Binford and Chasko (1976) detected what they called the "first major demographic transition" and which, in this volume, is called the NDT. They correctly identify its major cause – fertility and not mortality – along with its starting point at the end of Pleistocene. The fascinating aspect of this discovery, which did not receive the coverage it deserved, is that the demographic data on which it rests are very far removed, historically and ecologically, from Neolithic data, since they relate to the Nunamiut Eskimos of Central North Alaska. More interesting still is that, in the space of a single generation, from 1950 to 1965, the Nunamiut – who became sedentary at the same time as other geographically close Indian populations (Athapascan: Roth 1981, James Bay Cree: Romaniuk 1981) – successively experienced the explosive fertility of the NDT, followed by a collapse with the advent of the contraceptive practices of the CDT. The same is true of neighbouring populations. Binford and Chasko explore several avenues in attempting to account for this fertility explosion, from variations in coital frequency with the mobility of hunters to a dietary shift. They detect an influence of cereal consumption on fertility (Fig. 2) and conclude that this first demographic transition would have been a by-product of sedentarism and its impact on diet and the division of labour.

To these ethnographic data can be added palaeoanthropological data from cemeteries, which, although cannot be used to test the biodemographic assumption, do make it possible to test the proxy assumption of sedentism. Table 1 gives the values of the non-conventional demographic indicator $_{15}p_5$ for a set of nearly 20,000 skeletons from 138 cemeteries worldwide (Guerrero et al. this volume, Bocquet-Appel and Naji 2006, Bocquet-Appel 2002), which are divided into three mobility groups as indicated by archaeologists: nomadic (foragers), semi-sedentary (shell-midden foragers) and sedentary (farmers). A further breakdown of mobility is not
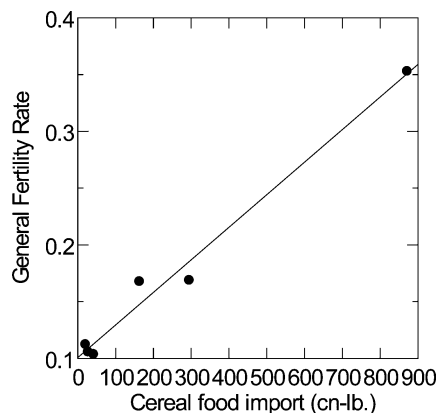

Fig. 2 Correlation between quantities of imported cereals and the general fertility rate among Nunamiut Eskimos (1949–1970). Note: From Binford and Chasko (1976, Table 10: 72 and Table 41: 129)

Table 1 Values of the paleodemographic indicator $_{15}p_5$ in three groups of cemeteries according to the degree of putative mobility

	Mobility		
	Nomadic (hunter-gatherers)	Semi-sedentary (shell-midden foragers)	Sedentary (farmers)
N sites	25	8	105
d(5–19)	715.92	147.30	4075.73
d(5+)	3213.02	642.50	16066.14
15p5	0.22282	0.22926	0.25368

(Sources: Bocquet-appel y Paz de Miguel Ibanez 2002, Bocquet-Appel 2002, Bocquet-Appel and Naji 2006, Guerrero, et al. this volume)

necessary for this exercise. We know that $_{15}p_5$ is highly correlated with the birth rate (r^2 adj. $= 0.963$: Bocquet-Appel 2002). We would therefore expect low $_{15}p_5$ values for nomads, intermediate values for semi-sedentary groups and high values for sedentary groups. The values of the demographic indicator $_{15}p_5$ are distributed in the expected direction (Table 1), ranging from $_{15}p_5 = 0.2228$ in nomads (foragers) to 0.2536 in sedentary groups (farmers). Table 2 gives the result of the validation test for the null hypothesis positing no difference in the $_{15}p_5$ proportion between paired groups. The difference is significant between the two most different mobility groups, i.e. hunter-gatherers (mobile) *vs*. farmers (sedentary) ($P = 0.0001$), with a lower indicator of expected birth rate in hunter-gatherers than in farmers, but it is not significant between the intermediate group of foragers (semi-sedentary) and each of the two other preceding groups. This test underlines, first, that not only the expected gradient of birth rate with mobility has been well observed in the archaeological data, but also the ambiguity of the demographic response of the intermediate semi-sedentary group attributed to the shell-midden foragers of the literature. This ambiguity is definitely accounted for by the test of relative metabolic load with the ethnographic data given below (see Table 3). Fertility remains uniformly low with a low-calorie diet of aquatic animals (fish and some shellfish), but rises when the energy constraint of mobility decreases.

Table 2 Probability of acceptance for the null hypothesis of equal $_{15}p_5$ proportions between paired groups. The corresponding data are in Table 1

	Nomads (hunter-gatherers)	Semi-sedentary (shell-midden foragers)
Semi-sedentary (shell-midden foragers)	0.367	–
Sedentary (farmers)	0.0001	0.151

Table 3 Fitting models (OLS) of demographic density (proxy for fertility) by the impact of diet b_1 (energy intake) and mobility b_2 (energy expenditure). In rows: diet category. Figure 4 provides 2D and 3D graphical representations of the data and the corresponding adjusted planes

	Constant (b_0)	t-value	Diet (b_1)	t-value	Mobility (b_2)	t-value
Hunting	−8.879	−2.737***	4.573	0.605	4.675	8.558****
Fishing	−5.667	−2.931**	−7.628	−2.691**	4.756	9.698****
Farming	−3.327	−1.816	29.553	5.942****	2.671	4.879****

P > |t|: *≤ 0.05, **≤ 0.01, ***≤ 0.001, ****≤ 0.0001

The Relative Metabolic Load Model

Taking a different angle, anthropological demographers and reproduction biologists are trying to understand the determinants of natural female fertility. Let us recall that for a fixed reproductive duration of roughly 35 years, the fertility level can be expressed by the duration of the birth interval. During the fertile life of a mother, when the duration of the birth interval increases, the number of children born decreases. The duration of the birth interval is inversely proportional to fertility. But the inter-population variation of the birth interval is large (Wood 1994). In the context of the shift to agriculture, three main assumptions can account for this variation in the birth interval. The first is maternal stress from transporting children, caused by the forager mother's inability to care for more than one dependent offspring at a time (Blurton Jones 1986, Blurton Jones and Sibly 1978, Binford 1968, Sussman 1972, Lee 1972a, b; Bleek 1928). The duration of the birth interval is a function of the distance covered by a mother and of the growing weight of a child. This assumption has produced contradictory results (Roth 1981, 1985; Vitzthum 1994).

The second assumption postulates (i) that the duration of the birth interval is an (inverse) function of the intensity and frequency of suckling (Konner and Worthman 1980, Wood et al. 1985, Diaz 1989, Lewis et al. 1991, Peng et al. 1998) and (ii) that suckling during the transportation of children by their mothers decreases during the transition on the mobility gradient from nomadic foragers to sedentary farmers (Bocquet-Appel and Naji 2006, Lee 1979, Sussman 1972). But several studies have shown no correlation between the intensity of suckling and the return of the reproductive cycle (Fink et al. 1992, Worthman et al. 1993, Tay et al. 1996). The third assumption is the relative metabolic hypothesis for maternal nutrition (Huffman et al. 1987, Lunn et al. 1984, Ellison et al. 1993, Ellison 1994, Valeggia and Ellison 2004). The duration of the birth interval is an (inverse) function of the energy balance (energy status and energy balance). The energy balance is determined by energy expenditure (on necessary milk production and physical activity) and postpartum energy intake (mother's diet).

Curiously, interpretations of the field data have been possible sometimes thanks to one of the assumptions, and sometimes to the other. But a recent study has produced a major advance in favour of the relative metabolic load model. In breast-feeding women with natural fertility, the date of resumption of the cycle

is determined by a positive return of the relative energy balance after childbirth and its stability for a period of about 3–4 months (Valeggia and Ellison 2004), the whole determining the duration of postpartum amenorrhea. In the remainder of this chapter, the variable representing the positive return of the relative energy balance *(EB)* is written as $\Delta_t EB + e$, with the index t indicating the positive return at time t after childbirth and e the stable duration of *EB* positive, ending with the return of the menses. Without additional studies, the stable duration of *EB* positive cannot be regarded as invariant between populations. The duration of postpartum amenorrhea is equal to $t + e$. The suckling frequency is a necessary but not sufficient signal determining the duration of postpartum amenorrhea. To this duration, in an anthropological context, we need to add the postpartum sex taboo, c, determined for cultural reasons. The whole gives the birth interval $t+e+c$. In ethnographic populations, the average duration of the postpartum taboo is shorter among mobile foragers than among sedentary farmers (see Table 4, Saucier 1972).

Valeggia and Ellison's data and their interpretation by their relative metabolic load model make it possible to take into account the intensity of suckling frequency and the maternal energetics required to ensure reproduction, in a given economic and ecological context. This in turn makes it possible to understand the reasons for the diversity of interpretations of the survey data, which sometimes control one variable and sometimes another. In the context of the shift from a forager to a farming economy, if the cursor for suckling frequency (high), energy status (regular in the context) and the postpartum sex taboo is kept fixed, we would expect input and output in the energy balance to be affected by

- a reduction on the input side in the proportion of low-calorie food items (tissues from hunted animals and fish) relative to high-calorie food items (wheat, lentils, peas, maize);
- a reduction on the output side in energy expenditure among foragers, via reduced physical activity involved in mobility and the maternal stress of child transportation.

Table 4 Mobility patterns (in columns) versus duration of post-partum abstinence (in rows). Sample of 201 populations of mobile foragers and sedentary farmers, from the 1267 populations in George P. Murdock's Ethnographic Atlas (Gray 1998; Murdock GP and White DR 1969) (see text for comment). Mobile foragers have a post-partum abstinence significantly shorter than sedentary farmers (χ^2 of homogeneity $= 11.18597$, with 5 df. $P = 0.047$)

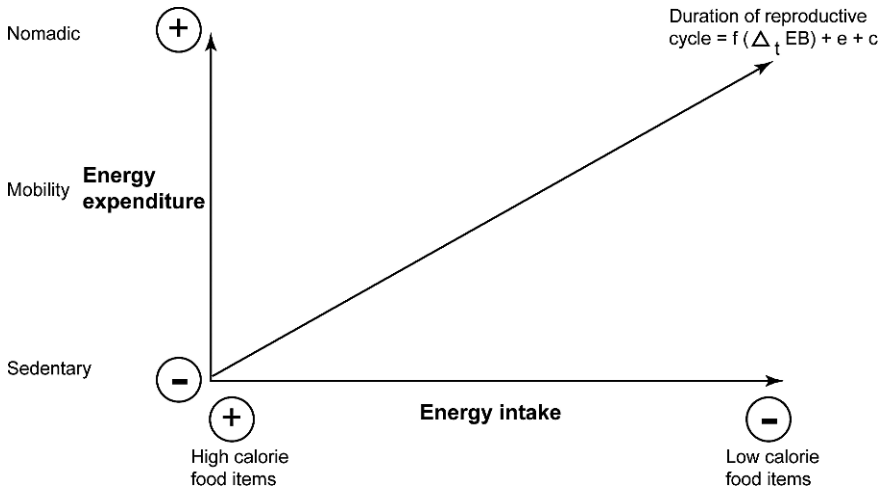| Time duration	Mobile foragers	Sedentary farmers	Total
None	0	7	7
≤ 1 month	9	22	31
1–6 months	17	40	57
6–12 months	4	19	23
12–24 months	7	36	43
≥ 24 months	3	37	40
Total	40	161	201

Fig. 3 Model of reproductive cycle duration. The diagonal line represents the lengthening of the reproductive cycle, expressed by the birth interval. The birth interval is determined by the time taken to reach a positive return of the relative energy balance *(EB)* after childbirth $(\Delta_t EB)$, by the stable population-dependent duration of *EB* positive *(e)* and by the postpartum sex taboo *(c)*. The energy balance is determined by (i) energy intake *(horizontal axis)*, ranging from low-calorie food items *(on the right, −: hunted animals, fishes)* to high-calorie food *(on the left, +: wheat, lentils, maize and peas)*; (ii) energy expenditure *(vertical axis)* represented by the physical activity corresponding to mobility and to the maternal stress of child transportation

This double effect on the energy balance results in a shorter duration of postpartum amenorrhea $(t + e)$, and thus to increased fertility. The fertility model determined by the relative metabolic load is represented in Fig. 3. We notice that its demographic effect is similar for sedentary populations using high-calorie food items, whether these are farmers or foragers such as the Natufians in the Levant (Fig. 3: position "+" on the horizontal axis of the energy intake and "−" on the vertical axis of the energy expenditure).

The predictions of this fertility model are tested with the data for the 172 ethnographic populations of Jorgensen's western North American Indian sample on their first European contact (1979, 1999). These data provide information on the density of consumed calorific energy, via the percentages of diet items (hunting, aquatic animals, agricultural produce) and physical activity, via a graduation of mobility (from nomadic, coded "0", to sedentary coded "7"). Information is thus given on demographic density (per mile^2), but none on fertility or the postpartum sex taboo. To test the fertility model with these data, two assumptions must be made. The first relates to the use of demographic density as a proxy variable for fertility. If the demographic regime of populations (determined by their inputs and outputs: birth rate, mortality and migration in and out) has not been disturbed in the recent past, their demographic densities will therefore mainly reflect their fertility. There are two

main causes of disturbance: (i) a variation in demographic density due to migratory movements (in or out), as in the contemporary examples of rural migration and concentration in megalopolises across the entire planet, and (ii) an abrupt negative or positive variation in the fertility of a population, but where the current demographic density is a reflection of its former fertility: an example is the Chinese population today, with its high demographic density and very low fertility. The assumption of an absence of major disturbance in the demographic regimes of the ethnographic sample prior to the first European contact seems acceptable. The second assumption relates to the postpartum taboo, whose duration is not indicated in the ethnographic data and which we might be tempted to regard as a random variable, independent of the demographic density. As seen above, it is not. Average postpartum duration *(c)* is longer in the relatively high-density populations of sedentary farmers than in mobile foragers. Paradoxically, when demographic density rises in these data, we should expect an undervaluation of fertility energetics. This will be looked into below.

The impact of mobility and diet on demographic density, used as a proxy variable for fertility, is tested by means of simple linear adjustments (OLS), $z = b_0 + b_1 x + b_2 y + h$, with *x, y, b* and *h*, respectively, representing, for energy intake, the proportion of a specific food (from hunting, aquatic animals and agricultural produce), for energy expenditure mobility, regression coefficients and an uncontrolled residue. The 2D and 3D representations of the models are given in Fig. 4.

A successive examination of the three diet categories (Table 3) shows the following:

– with energy intake from hunting (Table 3, line 1, Fig. 4a), i.e. from low-calorie food items, only energy expenditure (mobility) has a significant influence on fertility, which rises when energy expenditure decreases;
– with energy intake from aquatic animals (mainly fish and some shellfish, Table 3, line 2, Fig. 4b), there are two significant influences: a relatively weak negative influence of low-calorie food items and a strong influence of energy expenditure (mobility). Fertility rises when the low-calorie food items and the energy expenditure both decrease.
– with energy intake from farming produce (mainly maize, Table 3, line 3, Fig. 4c), the influences of energy expenditure and energy intake from high-calorie food items are both significant. Fertility increases more when, simultaneously, energy intake from high-calorie food items increases and energy expenditure decreases, with energy intake exerting a more perceptible influence than energy expenditure.

Allowing for a probable undervaluation of the fertility energetics in the ethnographic data when the demographic density rises due to the impact of the postpartum taboo as discussed above, the slopes of the adjusted planes in the graphs (Fig. 4) should be tilted a little more towards demographic density. To summarise, the relationships observed in the ethnographic data between the variables representing the relative metabolic load and demographic density, used as a proxy for fertility, all take the directions predicted by the fertility model. This is the message contained
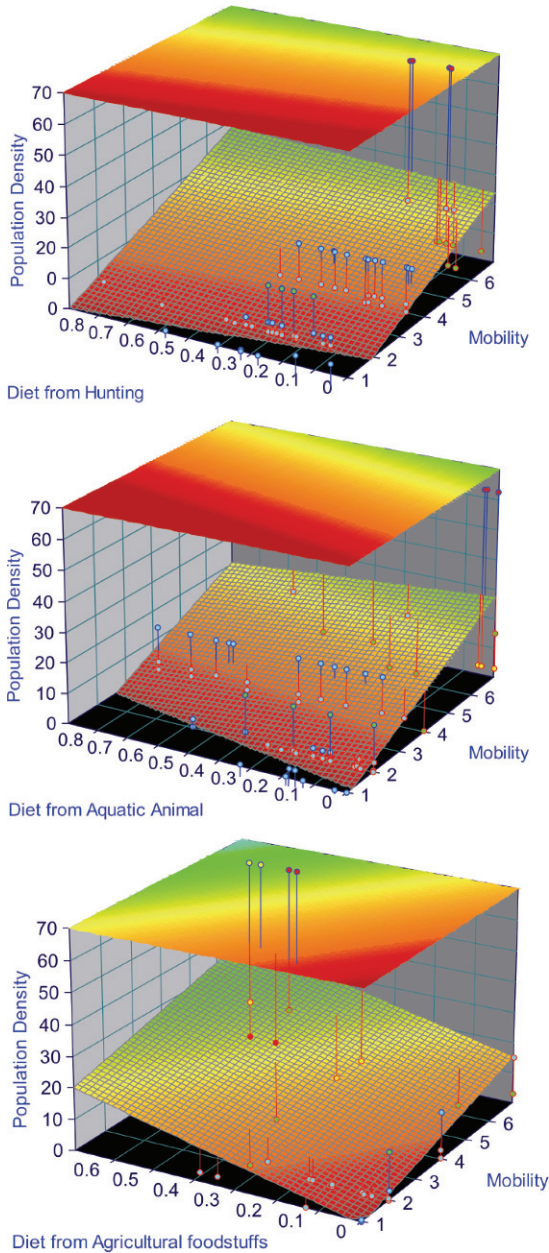
Fig. 4 3D representation of demographic density (proxy for fertility), accounted for by energy expenditure (mobility, from 0 = nomadic to 7 = sedentary) and energy intake (diet from (**a**) hunting, (**b**) aquatic animals, (**c**) agricultural produce) with the relative metabolic load model applied to Jorgensen's sample (1979, 1999) of western North American Indians on first European contact. A 2D representation of demographic density is given at the top of each graph. The statistical tests are given in Table 4
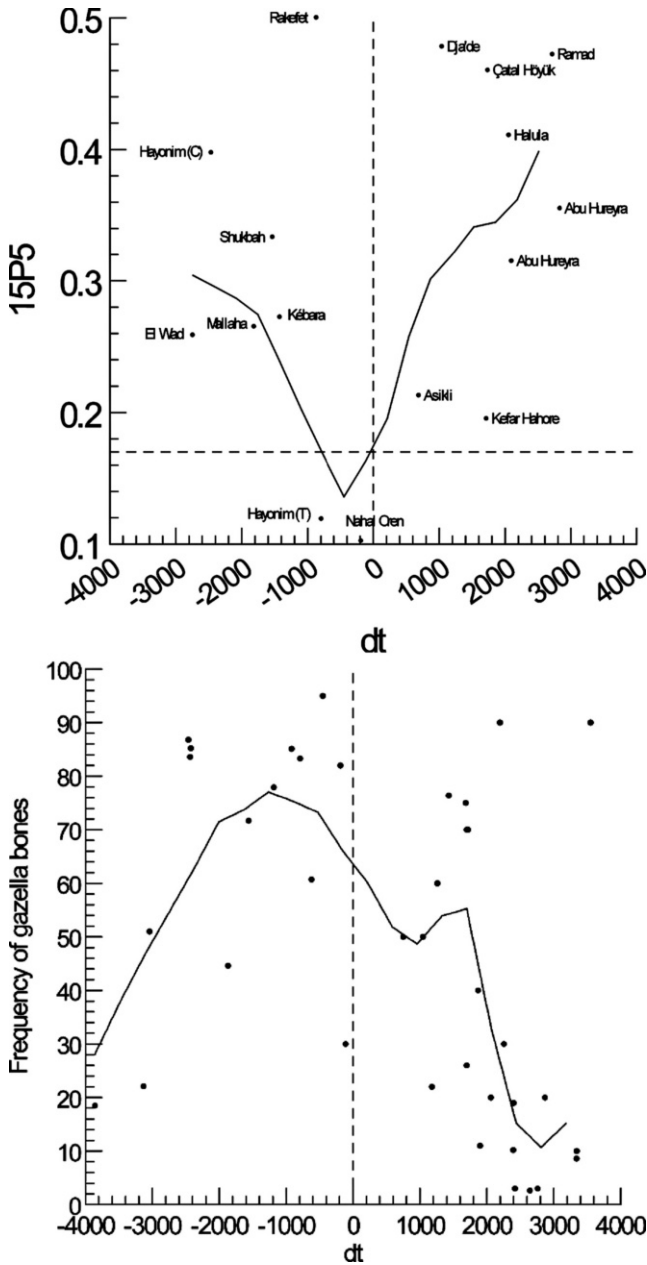
Fig. 5 Profile of variation in the Levant, in the relative chronology dt, in (*top*) the demographic indicator $_{15}p_5$ and (*bottom*) the proportion of gazelles in animal remains (two smoothers, DWLS, the smoothest, and Loess, the least smooth; same parameters alpha $= 0.5$; from Guerrero et al., this volume)

in the ethnographic data, which should help us to gain a better understanding of the cause of the NDT.

The interpretation of the $_{15}p_5$ profile of the NDT at the source of agricultural invention in the Levant can thus be taken further. Along with the increase in fertility, the signal of the NDT expresses a steady reduction in the duration of the reproductive cycle and, beyond this, of the positive return of the relative metabolic load. This reduction must have been determined relatively to the forager society, simultaneously by an energy intake comprising a decreasing proportion of low-calorie food items (hunting) and an increasing proportion of high-calorie food items (cultigens), as well as a reduction in energy expenditure accompanying sedentarisation. Figure 5 represents the profiles for the fertility transition in relative chronology (dt) and for hunting (Guerrero et al. this volume). These profiles show a negative correlation: when the share of hunting in the diet increases, fertility decreases, and vice versa. This is rather remarkable since the phenomenon covers two periods of increasing fertility/decreasing hunting (at $-4000\,d$t and $2000\,d$t). The coincidence of hunting profiles and demographic profiles in the Levant, over a relatively long duration, has already been noted (Guerrero et al. this volume). The fertility model can provide at least three explanations for the parallel direction of these profiles, one in terms of a reduction in energy expenditure, via reduced mobility, another in terms of a reduction in the proportion of low-calorie food items (represented by gazelles) with a probable correlative increase in high-calorie food items (represented by wheat, lentils and peas) or a combination of both. This last explanation seems the most likely. With regard to the reduction in energy expenditure, this certainly relates to the transportation of children. But with the growth of the population, the number of families, of individuals within families and of extended families also increases. This increase in average family size and in the number of extended families points to a probable supply of surrogate carers for the mothers, i.e. to more collective responsibility for taking on the physical constraints of motherhood and domestic activities during the nursing period, which causes a further increase in fertility.

Explorations of a New NDT Model

Long-Term Growth and Homeostatic Equilibrium: A Brief Reminder

As for other animals, demographic growth in human populations is regulated by density-dependent mechanisms (Reher and Ortega Osona 2000, Lee 1987, Blum, Bonneuil and Blanchet 1992; for a discussion, see Wilson and Airey 1999; for mammalians, see Sibly, Hone and Clutton-Brock 2003). Any significant variation, due to a disturbance, from the long-term average value of the birth rate *(b)* or mortality rate *(d)* will quickly return to near this average value. The difference between the birth and mortality rates corresponds to a population where demographic growth *(r)* is close to zero ($b-d = r \cong 0$). It is said of such a population that it is in homeostatic

equilibrium or that it fits the density-dependent model. If density-dependent reg-
ulation were absent, then any reduction in the population's growth rate could end
in extinction, while any increase could lead to an infinitely expanding population
(Sibly, Hone and Clutton-Brock 2003). This density-dependent pattern has been
detected in the archaeological data representing the increase in site density in Peru
(Bandy 2005). The near-zero value of the long-term growth rate of prehistoric popu-
lations is generally agreed upon (Hayden 1986, Hassan 1981, Dumond 1975; Boone
2002 countered) and is verified in the archaeological data (Bocquet-Appel, Demars,
Noiret and Dobrowsky 2005).

   A remarkable and well-documented fact in human demographic history is the
response of the metapopulation to the major disturbance represented by the CDT.
Across the planet as a whole, this transition has raised life expectancy at birth from
25 to 70 years and lowered the average number of children per woman (TFR) from
8 to 2 or less in just three centuries. Against the backdrop of the density-dependent
model, the CDT has to be seen as a very large-scale disturbance with intrinsic causes
(see below), whose return time to homeostatic equilibrium towards a zero growth
rate in the endogenous geographical zones of invention was proportional to the scale
of the disturbance. This transition lasted nearly 250 years in the UK and 150 years
in Denmark. It must be remembered that the scenario of the CDT was a transition
towards lower mortality, followed by a transition towards lower fertility (Fig. 6). The
pattern of this global transition is therefore, in fact, of two superimposed transitions
that vary together, with a greater or lesser time-lag. The CDT is the only known
historical reference pattern of a major demographic shift (other than induced by
a catastrophe) representing a demographic transition. It is therefore legitimate to
compare these two transitions, the NDT and the CDT, which, in terms of the scale
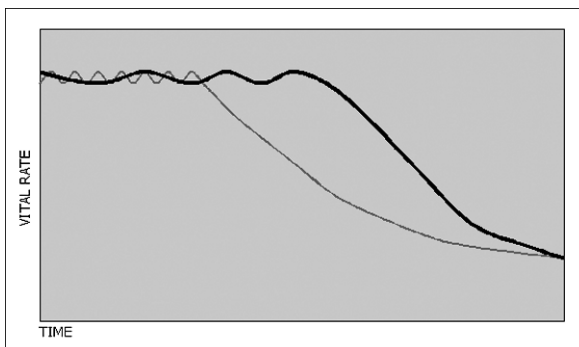of their impact on human evolution, are of the same order.

Fig. 6 Model of contemporaneous demographic transition. From a value of about 40 per 1000
before the transition, we see a drop in the death rate (*in grey*), followed by a drop in the birth rate
(*black*), down to approximately the same value as the death rate, after a variable duration of about
250–150 years

Lessons from the NDT and CDT Comparison

First of all, as indicated above, compared to the CDT, only the fertility transition profile for the NDT is observed from cemeteries data, but the mortality transition is missing. We then see that the direction of the fertility transition is reversed, tending towards higher values for the NDT and lower values for the CDT. This reversal has led me to formulate the assumption of an NDT pattern that is a mirror image of the contemporary transition, both in the order of the demographic variables (*b* followed by *d* in the NDT, and not *d* followed by *b* as in the CDT) and in their directions (transitions towards increasing and not decreasing values). Therefore, the scenario begins as follows: for reasons due to the demographic densification of the foragers' world (Cohen 1977), which determined ecological pockets of sedentism in Eurasia at the end of Pleistocene and in Mesoamerica around 4500 BP, the transition towards an increase in fertility would have begun, followed by a mortality transition towards these same high values, for the reasons of homeostatic equilibrium indicated above. The important question is the tempo of this return to equilibrium, during which there would have been an appreciable growth in the population.

Figure 1 represents the profiles of the fertility transition in the NDT observed in 133 sites in the northern hemisphere (no Levantine sites). From the relationship between $_{15}p_5$ and the birth rate given by the estimators of the pre-industrial model (Bocquet-Appel 2002), life expectancy at birth, average number of children (TFR) and females surviving to mean childbearing age can be estimated using the assumption of a stationary population, for example with Coale's chart (1974: 45). This chart uses the different relationships between TFR, NRR and a growth rate set at zero (Hinde 1998: 187, Pressat 1972: 350–352). Table 5 gives the values of these different demographic variables on the average profiles ($_{15}p_5$) of the fertility transition in the northern hemisphere (Fig. 1), at $d\mathrm{t} = 0$, marking the onset of the NDT, and at $d\mathrm{t} = 1000$, the first plateau of the $_{15}p_5$ profile marking the end of the transition. The estimated birth rate is 40.3 per 1000 at $d\mathrm{t} = 0$ and 53.1 per 1000 at $d\mathrm{t} = 1000$. The large differential of the two values indicates that the return to the equilibrium could not occur at the end of the fertility transition, otherwise the number of humans would have become unrealistically enormous. To reconcile a birth rate (fertility) that rises slowly but continuously for 1000 years with a realistic growth rate slightly above zero (about 0.2%), which is typical of pre-industrial populations, mortality must

Table 5 Estimated values for different demographic parameters using Coale's relationship (1974: 45), starting from the birth rate estimate given as input data using the paleodemographic estimators ($_{15}p_5$) for the pre-industrial model (Bocquet-Appel 2002)

$d\mathrm{t}$	$_{15}p_5$	Birth rate (1)	TFR (2)	e_0 (3)	Surviving females % (4)	Growth rate
0	0.200	40.3	5.2	24.8	39.4	0.
1000	0.300	56.2	7.2	18.3	28.5	0.

(1) Birth rate per 1000. (2) Total fertility rate (births per female). (3) Life expectancy at birth. (4) Females surviving to mean childbearing age (%).
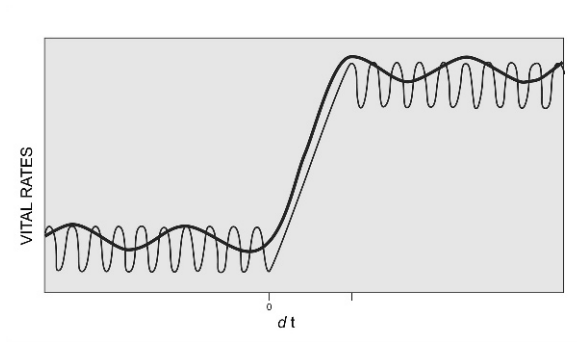
Fig. 7 Model of the Neolithic demographic transition. In this model, a fertility transition towards higher values (*in black*), driven by sedentism, appears at the onset of the new economic system, at $dt = 0$. But a mortality transition soon follows, also towards higher values (*grey*), driven by the density of village life and contamination (drinking water, latrines) associated with zoonoses, as well as by a change in nursing patterns. In a similar model published by Coale (1974), the two transitions are reversed compared to the model presented here

rise at approximately the same rate. This model is shown in Fig. 7. At this rate of increase, the population doubles in 350 years.

In this model (Fig. 7), the birth rate (and fertility) rises continuously, determined by the age pyramid and age-specific fertility rates, which (with the TFR) increase as a result of a shift in maternal energetics. With the growth of the population, the number of surrogate carers also increases (grandparents, older children), which may have helped to increase fertility. The maximum stable birth rate (53 per 1000) may have been reached when, in the farming system, maternal energy expenditure on physical activities fell to a minimum as it became integrated into the overall workings of the social system, while energy intake rose to a maximum through the incorporation, thanks to regular and stable supplies, of the high-calorie food items now being selected.

Causes of the Increase in Mortality

With sedentary village life and the corresponding growth in local population density, mortality rates inherited from the foragers eventually rise, particularly in children under 5 years of age. Causes of increased infant mortality would include lack of drinking water supplies, contamination by faeces and the absence of latrines, as well as reduced breastfeeding. The susceptibility of humans to new infectious diseases results from complex factors such as modified exposure to animals, microbial adaptation, nutritional status and density of the host population. The high proportion of children in Neolithic burial sites could have resulted from the emergence of highly virulent zoonoses that were newly acquired. Interestingly, however, it can be seen that the variation in the proportion of skeletons aged 0–4 years in cemeteries, set within the frame of the relative chronology dt, mimics the proportion of 5- to
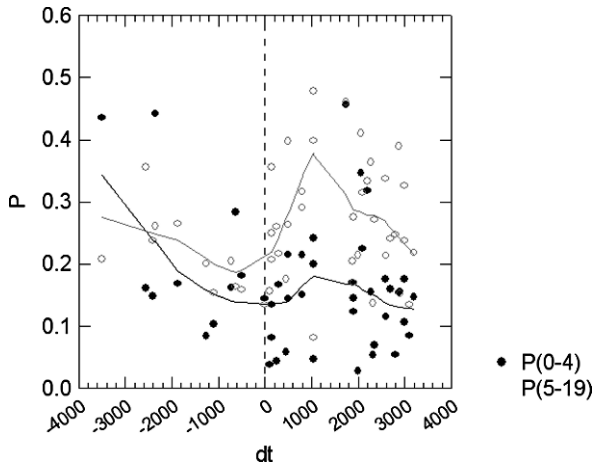
Fig. 8 Variation in the profile of the proportion of 0 to 4 year-old immature individuals, P(0–4), and 5 to 19 year-olds, P(5–19), obtained with the Loess fitting procedure. Both profiles show the same signature of the NDT pattern

19-year-olds, in spite of the taphonomic impact (see Fig. 8). This role of infectious diseases in the homeostasis of population growth is still mainly hypothetical. Molecular analyses of the divergence between related animal germs are only an indirect way of assessing their period of acquisition by humans. Candidate germs by "epidemiological inference" from current pre-industrialised areas and those with poor health facilities should include germs associated with animal domestication, such as *Paramyxovirus* (measles), *Poxvirus* (smallpox), *Rotavirus* and *Coronavirus* (diarrhoea, one of the main killers of children under 5 years of age), *Streptococcus* (including *Streptococcus agalactiae*, linked to cattle milking) or *Staphylococcus*. Some germs believed to co-evolve with humans should also be studied, such as *Plasmodium* (*P. falciparum*, and *P. vivax*, which is believed to have emerged more recently) or *Herpesvirus*. But only diseases involving a haematogenic process will be easily detected. Research in molecular anthropology should provide information in this promising area (Mira, Pusker and Rodriguez-Valera 2006). During the NDT, the population may have lost several years of life expectancy. Finally, mortality stops rising once the regional density and concentration of the population have stabilised.

A model of a Neolithic transition, graphically resembling of the one in Fig. 7, has been published by Coale (1974) but, contrary to the model put forward here, "the death rate increased as a result of greater susceptibility to disease in village life, and perhaps also because agriculture is vulnerable to climatic crises. If the death rate did increase, then it is certain that the birth rate also rose, and by a slightly greater margin" (Coale: 48). In Coale's model, the increase in the birth rate does not have any explicit cause other than homeostasis. This question as to which variable, the birth rate or the mortality rate, initiated the NDT is not a chicken-and-egg problem. The

idea that demographic growth in the Neolithic, which was without historical precedent, could have been triggered by an increase in mortality is bizarre. To sustain a village life, the population had to reach a certain number and this number could only be achieved through an increase in fertility. Rising mortality, as the population density increased, could only come after, and not before, the initial population growth. Seeing an increase in mortality as triggering demographic growth is like starting off a race by making the runner shoot herself in the foot: she will not run far. But Coale has correctly thought out the constraint weighing on the increase in these rates: they must follow each other closely for the growth rate to remain viable.

Some Expected Demographic Consequences of the NDT

During the NDT, with the tempo at $dt = 1000$ years (Fig. 1), although fertility increased considerably (the estimated TFR increased from 5.2 to 6.8 children per woman), average family size increased only moderately, from 4.3 to 4.7 people, because of the increase in mortality; the size of households including one of the two surviving grand-parents more than 60 years of age rose from 5 to 5.2 people. At the onset of the NDT, life expectancy at birth could have been about 24 years for males and 25 years for females, but rises to 33.6 years and 34.1 years, respectively, at the age of 20. By the end of the NDT, due to the transition to higher mortality values, life expectancy at birth is about 18 years in both sexes, but 28 years for males and 29.5 years for females at the age of 20; 55% of the population is under 20 years old and the median age is 17. These figures must be taken rather as orders of magnitude in order to try to indicate the trend during the NDT, rather than precise statistical data.

What consequences should we expect from a very young population, with a birth rate and a median age identical to that of Niger today (57 per 1000 in 1977: Direction de la statistique 2003)? One of the effects of an increase in the growth rate caused by a combination of high birth and mortality rates is that families, on average, have more surviving children but families do not last as long. In societies with low life expectancy at birth, extended families, first to collaterals, are taken as the standard relative to nuclear families, with "their patriarchal or matriarchal and nepotistic tendencies that stifle individual initiative" (Kuznets 1965: cited by McNicoll 1984: 214). To individuals, mainly children, they provide a form of life (or survival) insurance when mortality causes families to fall apart. In many traditional village societies, the inhabitants make a distinction between the descendants of the original founders of the village and other inhabitants who do not have this ancestral link (McNicoll 1984).

Villages have historically expanded by fission in most peasant societies, with the establishment of "daughter villages" as population grows. The resulting pattern of clustered hamlets, each village typically having a few hundred homes at most, is largely found in Asia and the Middle-East. In the context of open borders, the inhabitants can create new villages in distant settlement areas.

Concluding Remarks

The cause of the Neolithic fertility transition put forward in this article, beyond the proxy variable represented by sedentism, is the impact of an unprecedented shift in the energetics of female mobile foragers over 3000 years in the Levant. However, this unprecedented increase in fertility did not result in demographic saturation of the planet as might be expected but, probably only in a growth rate typical of pre-industrial populations of about 0.1–0.2%. The hypothesis is therefore that, with the appearance of village life and the corresponding increase in local population density, higher mortality soon followed the increase in fertility. This would have produced the net effect of an appreciable increase in the population during the NDT and, at the same time, a reduction in life expectancy at birth. The difficulty, however, lies in detecting the signal of the mortality transition in the (bio)archaeological data available. This is the first new challenge.

A new question relates to the insights provided by the NDT scenario that help us to understand the archaeological data, and vice versa. At which point in the timing of the fertility transition did archaeological artefacts appear, or disappear, that are interpretable in terms of indicators of economic, social and ideological reorganisation or adjustment? What changes in the archaeological data can be linked to the tempo or the scenario of the NDT? (for a review see Kuijt 2000a, Kuijt and Goring-Morris 2002). The second challenge is the integration of the archaeological data (Kuijt and Goring-Morris 2002, Belfer-Cohen and Bar-Yosef 2000, Kuijt 2000a, 2000b) into the model of the NDT and the reverse, in order to understand the multidimensional aspects of the first human experiment in unprecedented population concentrations and the birth of a New world.

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